Technological Externalities and Common-Property Resources: An Empirical Study of the U.S. Northern Lobster Fishery
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Source: *The Journal of Political Economy*, Vol. 80, No. 1 (Jan. - Feb., 1972), pp. 148-158
Published by: The University of Chicago Press
Stable URL: http://www.jstor.org/stable/1830137
Accessed: 13/07/2009 17:01

Technological Externalities and Common-Property Resources: An Empirical Study of the U.S. Northern Lobster Fishery

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This paper demonstrates the effect of technological externalities on the production of northern lobsters, a common-property resource. An increase in effort (that is, size of the industry) of 100,000 traps fished will depress landings per trap for the individual firm by 2.4 pounds. Therefore, the northern lobster industry produces so as to equate average revenue to long-run average cost. Approximately one-half of the present fishing effort would be needed to achieve economic efficiency or marginal cost pricing. The goal of allocative efficiency should be weighed against the strategy to provide somewhat greater employment, especially in rural areas where labor opportunity cost is relatively low.

I. Introduction

Technological external diseconomies cause the long-run supply curve to be upward sloping. This is usually the case in which the firms in an industry use a resource that is free, but nevertheless scarce, such as a publicly owned road, a common geological oil field, or fish in the ocean.[1] Typically, a rising-cost common-property industry operates at an output level above the social optimum since its marginal social cost of production exceeds its marginal private cost. Forcing a rising-cost industry to contract so as to equate marginal social and private cost would represent a saving of resources.

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[1] The traditional literature came of age with Pigou's *Economics of Welfare* (1932). The first satisfactory distinction between technological and pecuniary economies seems to have been made by Baumol (1952). Worcester's article (1969) is an excellent survey of the theoretical implications of technological externalities.

The purpose of this paper is to demonstrate the effect of technological externalities on the production of northern lobsters, a common-property resource. We shall show the social savings that might result from contraction in the lobster fishery. Because the maximum potential of the valuable lobster resource is fixed by biological parameters, we shall discuss the potentially destructive influence of the common-property nature of the resource. Also, the effect of physical environment on productivity will be explored. Hopefully, this paper will serve as one of the first empirical verifications of the common-property theories developed by Gordon (1954) and Scott (1955).

II. The Industry Production Function for Northern Lobsters

The New England lobster industry has existed in one form or another for centuries. The inshore northern lobster fishery ranges from Labrador to Delaware, with catches being most abundant in the rocky coastal zone from the Gulf of Saint Lawrence in Canada to southern New England. The fishery is largely based upon fishing wooden traps or pots in inshore areas. This technology has not changed for decades. In 1966, New England fishermen received approximately $25.6 million for their catch of northern lobsters, which are marketed live throughout the United States.

To properly understand the industry production function for the northern lobster resource, we must first specify a biological growth model. If there were no fishing (no intervention in the ecosystem by man), the growth of any species or population is hypothesized to follow a logistic growth curve as discussed by Schaefer (1954):[2]

$$N_t = \frac{N^*}{1 + be^{-at}}, \tag{1}$$

where N = the population size (weight); t = time; and N^* = the maximum population consistent with food supply, space, and other environmental factors, while a and b are parameters. If we differentiate (1) with respect to time and multiply through by N^{-1}, we have the rate of change in the population expressed as a function of the population size:

$$\frac{dN}{Ndt} = a(N^* - N_t). \tag{2}$$

If man intervenes in such a system, we may express (2) as

[2] The rate of growth in any population is the difference between natural growth (reproduction) and mortality. For a fishery, additions to the stock are determined by recruitment (those individuals large enough to be considered fishable) and growth, while reductions in the stock are determined by natural mortality (as opposed to man-made mortality).

$$\frac{dN}{Ndt} = a(N^* - N_t) - F(E) + U_t, \tag{3}$$

where the function, $F(E)$, represents the rate of loss of the fish population due to fishing effort (E)—inputs of capital and labor—or man-made mortality and U_t is a random error term. The latter term reflects random changes in the external environment such as water temperature, salinity, winds, etc. Assume further that $F(E)$ is proportional to fishing effort (E), (rate of loss is proportionately higher with greater effort):

$$F(E) = kE_t. \tag{4}$$

Substituting (4) into (3) and solving for a steady state solution (equilibrium between growth and man-made mortality or $dN/Ndt = 0$), we have,

$$0 = a(N^* - N_t) - kE_t + U_t. \tag{5}$$

At any point in time, the catch, Q_t, by man may be expressed as the rate of man-made mortality multiplied by the population size, or

$$Q_t = kE_tN_t. \tag{6}$$

Solving (6) in terms of N_t and substituting into (5), we have a steady-state relation between catch and effort (inputs of capital and labor):

$$Q_t = kN^*E_t - \left(\frac{k^2}{a}\right) E_t^2 + \frac{kU_t}{a} E_t. \tag{7}$$

Hence, the industry production function is hypothesized as a parabolic relation between output and inputs (fishing effort). Also, differentiating (7) with respect to Q and setting equal to zero, we find that there is a specific quantity (designated $E_{\max}$) of capital and labor (effort) associated with maximum sustainable yield (MSY) from the resource ($Q_{\max}$), or

$$E_{\max} = \frac{kN^*}{2k^2/a} = \frac{N^*a}{2k}; \tag{8}$$

$$Q_{\max} = \frac{k^2N^{*2}}{4k^2/a} = \frac{N^{*2}a}{4}. \tag{9}$$

Dividing (7) by E, we have

$$\frac{Q_t}{E_t} = kN^* - \left(\frac{k^2}{a}\right) E_t + \left(\frac{k}{a}\right) U_t. \tag{10}$$

Equation (10) demonstrates that the average productivity of a unit of effort (capital and labor) is an inverse linear function of the aggregate effort applied to the fishery. Put differently, the production function of the firm is dependent upon the aggregate number of firms in the industry. All firms, in effect, exploit a common-property resource which is free, but nevertheless scarce. Therefore, the catch rate, Q/E, is given to the firm (exogenous or external) by the total number of firms exploiting the resource.

This is a classic case of a technological externality. Notice in (10) that we are implicitly assuming that N^*, k, and a are fixed parameters. As stated above, the external environment may exert a random influence on the catch-effort relationship over a long period of time. Others such as Dow et al. (1961) have shown that the ultimate size of a northern lobster is greatly influenced by seawater temperature. Therefore, we shall hypothesize that N^* is positively influenced by seawater temperature and include the latter as an explicit independent variable in (10) (removing the influence of seawater temperature from the random error term):

$$\frac{Q_t}{E_t} = kN^* - \left(\frac{k^2}{a}\right) E_t + b°\mathrm{F} + \frac{k}{a} U_t, \tag{11}$$

where °F = mean annual seawater temperature (Fahrenheit). It should be clear to the reader that seawater temperature cannot increase productivity indefinitely but does have a marked influence within the relevant range of observations. If °F is held constant, N^* will be a fixed parameter (fixed constant at a given level of °F).

III. Empirical Estimation of the Industry Production Function

The northern lobster fishery has been using the same technology for decades. Production from the fishery is based upon fishing traps or pots from small one- or two-men boats. Each full-time boat fishes from 500 to 600 traps. The peak season is in the summer, with landings falling off during the winters as part-time fishermen are attracted to other pursuits. With this brief description of production, let us use the model developed in the last section.

The parameters of (11) were estimated using ordinary least squares for the period 1950–66 (t-values in parentheses):

$$\left(\frac{Q}{E}\right)_t = -48.4 - 0.000024\, E_t + 2.13°\mathrm{F}_t$$
$$(-1.43)\ (-3.37)\ (3.58) \tag{12}$$
$$R^2 = .96 \qquad \text{D-W} = 2.05$$

where Q = annual landings of northern lobster; E = annual number of traps fished; °F = mean annual seawater temperature, Boothbay Harbor, Maine.

Observations on Q and E were obtained from *Fishery Statistics of the United States* (1950–66), while °F was obtained from Dow (1967, unpublished manuscript). Both E and °F are statistically significant at the

5 percent level and exhibit the hypothesized sign. There is no evidence of autocorrelation in the residuals. According to our calculations, an increase in effort of 100,000 traps fished will depress landings per trap fished by 2.4 pounds. This is the quantitative effect of the technological externality. The effect of the environmental variable, seawater temperature, is quite marked. An increase of 1°F increases yield per trap by 2.13 pounds on an annual basis. Using the average yield per trap over the 1950–66 period, a 1°F increase in temperature would increase productivity (Q/E) by about 5 percent, holding the average level of effort constant. Figure 1 shows the separate effects of seawater temperature and effort on the industry production function for northern lobsters. Within the relevant range, higher permanent temperatures mean higher yields.

The 1966 level of seawater temperature is very close to the average prevailing over the last sixty-five years. If we insert the 1966 level of water temperature (°F = 46.0) in (12), and multiply through by E, we obtain a new yield function holding temperature constant (an isotemp curve):

$$Q = 49.4E - 0.000024E^2. \tag{13}$$

Using (8) and (9) we have the following: $E_{max} = 1{,}029{,}962$ traps fished per annum; $Q_{max} = 25.459$ million pounds of lobsters landed per annum. The 1966 observed level of effort was 947,113 traps fished, which is just

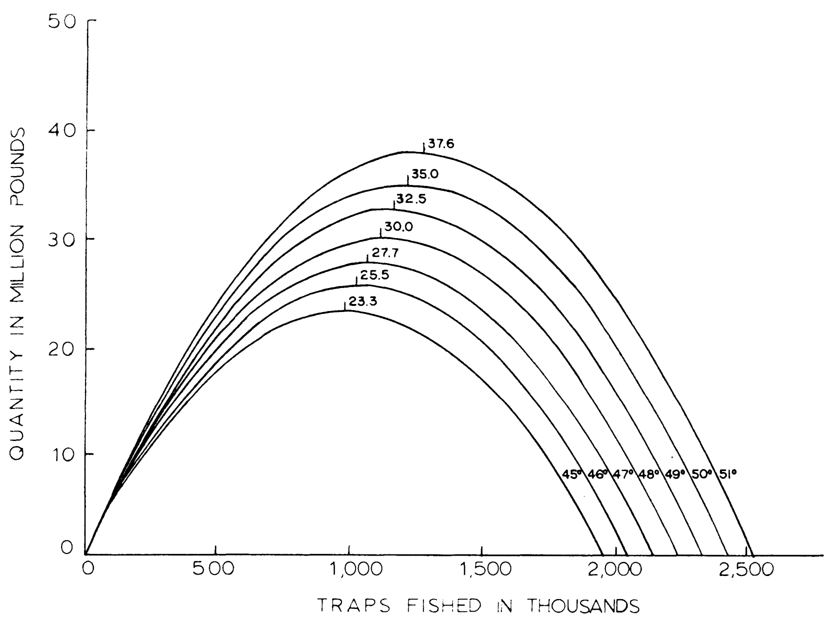

FIG. 1.—Relation of U.S. inshore northern lobster landings to fishing effort and seawater temperature, 1950–66.

under that level estimated to take the maximum sustainable yield from the fishery for that isotemp. The conclusion reached in the rest of this paper will apply to the 1966 seawater temperature.

This adequately describes the production side of the northern lobster industry. Now, let us consider the cost curves for the production of lobsters.

IV. The Industry Marginal and Average Cost Functions

Using the relation developed by Gordon (1954), we may specify that total industry costs (TC) is a linear homogeneous function of effort,

$$TC_t = cE_t, \tag{14}$$

where c is the average cost per unit of effort. That is, total cost per trap and for the industry per year is given by input prices and are not related to the size of the biological population. This is an unusual cost-output relation due to the externality problem where the cost of effort is independent of catch rates. Catch rates are determined by the total number of traps fished, which is exogenous to the individual fisherman. Since effort is a proxy for all factor inputs, c represents input prices including opportunity cost of capital and labor. Using a survey of costs of effort in 1966 conducted by the Bureau of Commercial Fisheries, we estimated $c = \$21.43$.[3] Thus, it costs approximately \$21.43 per trap to fish it per annum. The industry long-run average-cost function for 1966 may be expressed as the following, using (13) and (14):

$$LRAC = \frac{TC}{Q} = \frac{\$21.43E}{49.4E - 0.000024E^2} = \frac{\$21.43}{49.4 - 0.00024E}. \tag{15}$$

Solving (13) in terms of E and substituting into (15), we have long-run average cost as a function of output:

$$LRAC = \frac{\$21.43}{\left[-49.4 \pm \dfrac{\sqrt{(49.4)^2 + 4(-0.000024)Q}}{2}\right]}. \tag{16}$$

The total cost function in terms of Q may be obtained by multiplying

[3] The average cost of effort was computed by the following procedure: (1) Financial statements of a representative sample of fifty lobster vessels were selected. (2) From these data and other prices of inputs, opportunity cost was computed for all elements of costs, including ice, fuel, repair and maintenance, wages, and returns to capital. (3) The total computed opportunity cost for the sample was divided by the number of traps fished to obtain an estimate of average cost per unit of effort for the entire industry. Labor cost amounts to approximately \$5,200 per man annually and is over 43 percent of total cost.

(16) by Q. The resultant function may be differentiated to obtain the long-run marginal cost function, or

$$LRMC = \frac{\$21.43}{\sqrt{(49.4)^2 + 4(-0.00024)Q}}. \tag{17}$$

The long-range average and marginal cost functions for northern lobsters (1966) are shown in figure 2. Because of the technological externalities

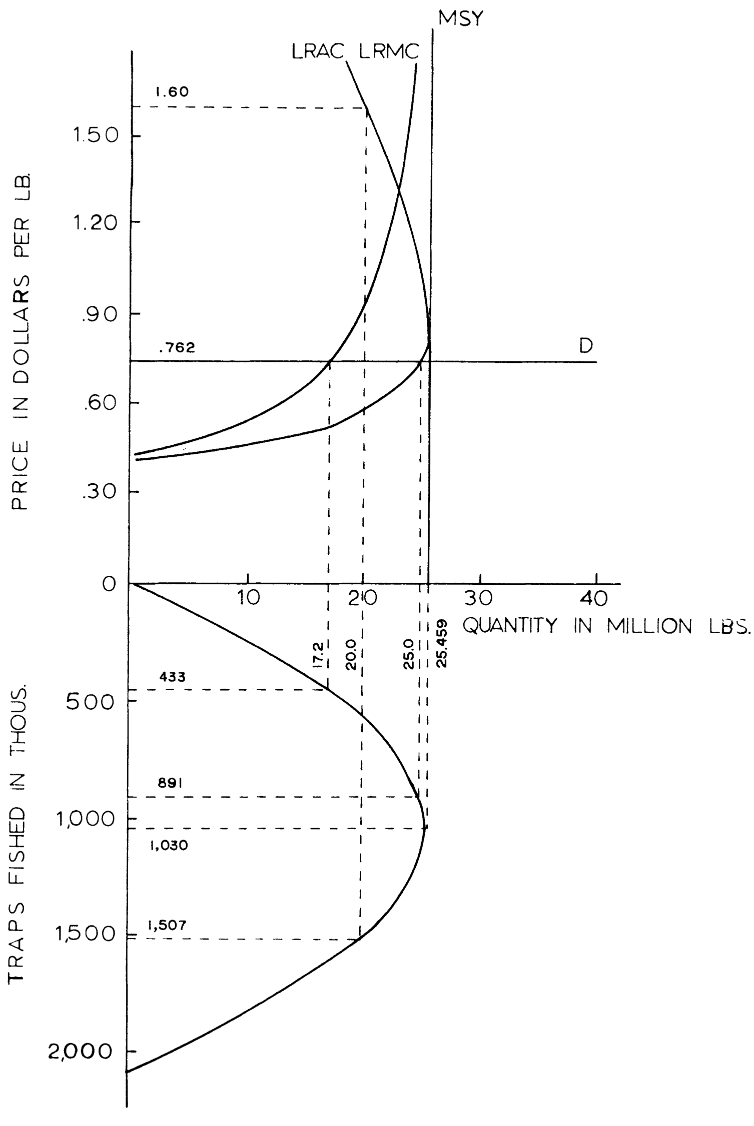

FIG. 2.—Relation of marginal and average cost to landings and fishing effort for the inshore northern lobsters, 1966.

and the maximum sustainable yield (*MSY*) from the resource, these functions exhibit a behavior quite different from normal cost functions. First, the technological externality produces a rising-cost industry throughout expansion, in contrast to manufacturing industries where long-run average cost first declines and then increases. Second, after reaching *MSY*, the average-cost function bends backward, since additional effort will produce a reduction in output at higher unit costs. The same conclusion was reached by Copes (1970) in his theoretical analysis of the fishing industry. Third, the long-run marginal cost is positive up to *MSY*. In fact, *LRMC* is asymptotic to *MSY*. Once the level of effort exceeds E_{max}, there is a reduction in output, and marginal cost becomes undefined. That is, the marginal cost of an additional unit of output cannot be defined since output contracts after E_{max} is reached.

V. Production under Free Access to the Resource

The output of the inshore northern lobster fishery represents about 14 percent of U.S. consumption of all lobsters. Lobster prices are, in essence, determined in an international market where prices are given to the regional fishery. For purposes of simplification, we shall assume an infinitely elastic average revenue curve for the regional inshore lobster fishery. In 1966, the ex-vessel price of northern lobsters was $0.762 per pound. Figure 2 demonstrates the level of lobster production under the price and cost conditions facing the fishery. As shown by Gordon (1954), the industry will produce so as to equate average revenue (*AR*) to average cost (*LRAC*). That is, since the lobster fishery is subject to technological externalities and hence rising *LRAC* and *LRMC*, marginal cost pricing will always result in economic rents (difference between marginal and average cost at any production level). Because of the common-property nature of the resource and short-run economic rents produced by *MC* pricing, firms will enter and thereby dissipate rents. The final stable long-run equilibrium will be at the point where $LRAC = AR$. Figure 2 shows that under the conditions existing for 1966, 25 million pounds of lobsters were produced with 981,000 traps fished per year (predicted by the model).[4]

Because of the common-property nature of the resource, "overfishing" is very likely (being on the backward sloping part of the *LRAC* curve shown in fig. 2). For example, if lobster ex-vessel prices were to increase to $1.60 per pound, this would entice 1,507,000 traps into the fishery (an increase of 616,000 traps over the 1966 level). The result would be a reduction in output to 20 million pounds, as indicated by the dotted

[4] The observed landings for 1966 were 25.6 million pounds and 947,000 traps fished.

line in figure 2. Unless entry to the common-property resource is controlled, further increases in prices because of rising consumer demand for lobsters could potentially destroy the resource as more and more capital and labor are attracted to the fishery.

VI. The Optimum Management Strategy

The optimum management strategy for any fishery is to permit effort to expand to the point where the marginal cost of the resources (capital and labor) needed to produce a pound of fish is equal to the price consumers are willing to pay for that last pound of fish produced.[5] The strategy of marginal cost pricing will insure that (1) economic efficiency will be achieved, and (2) the resource will not be exploited beyond maximum sustainable yield. For the inshore northern lobster fishery (in 1966), marginal cost is equal to price at a production of 17.2 million pounds (for 1966). According to the calculations, the level of effort needed to achieve this optimum would be approximately 433,000 traps. Therefore, we have reached the conclusion that over 50 percent of the capital and labor (458,000 excess traps fished) employed in lobstering represent an uneconomic use of factors. This implicitly assumes that these factors could be readily transferable, which may not be the case. In fact, the opportunity cost for labor is extremely low in rural parts of Maine. Therefore, labor is not easily transferable, and our conclusion regarding uneconomic use of resources should be qualified.

One management strategy which has often been suggested is to control effort at the point of maximum sustainable yield from the fishery. Let us consider why this may be a suboptimal strategy. For the inshore lobster fishery, if we allow effort to expand to maximize production, the marginal cost of the resources (capital and labor) used to exploit the fishery will exceed the average revenue from the fishery. Compared with the optimal position (marginal cost pricing), the maximization of production results in a net loss to society. The excess cost represents the area above the AR curve but under the marginal cost curve between the production of 17.2 and 25 million pounds. When we maximize production we are not conserving capital and labor but wasting these resources, since their marginal cost exceeds their dollar returns. In using the term "waste" we assume that these resources could be allocated to other pursuits in the economy where their returns would be equal to their marginal cost. In the short or intermediate period, this assumption may not

[5] The maximization of economic rent has been suggested by some as the optimal management strategy. For a regional fishery such as northern lobsters, MC pricing is identical with maximizing rent ($MR = AR$). If the demand curve were downward-sloping, we would not maximize economic rent, since this would be a suboptimal monopoly solution.

hold. As pointed out above, labor opportunity cost is very low in areas like Maine. Therefore, we must balance "economic or allocative efficiency" with a strategy to provide somewhat greater employment. The regional problems may dictate that a contraction of the fishery is, on net, not socially desirable. This is likely to be the case for many natural resources which are common property in nature.

It should be pointed out that the maximization of production and marginal cost pricing strategies discussed above practically coincide after demand for the fishery product reaches a certain level. That is, the marginal cost curve is asymptotic to maximum sustainable yield. This leads to an important truth: At high levels of consumer demand, the maximization of production and marginal cost pricing for all practical purposes are identical strategies. The coincidence of these strategies at high levels of demand is an extremely important point to remember since it considerably reduces the complications of administering a management program (finding that level of effort which equates marginal cost to price). This conclusion may also solve an age-old debate between biologists (and conservationists) and economists as to the proper management strategy with respect to output levels. Biologists and economists can now agree that *MSY* is a good objective at high levels of consumer demand. It should be noted that Copes (1970) indicates that the fishing effort required for a social optimum will come closer to that required to take maximum sustainable yield than will the more limited output levels.

VII. Conclusion

In this paper we have demonstrated how technological externalities flow from a common-property resource. This in turn produces a rising-cost industry where economic efficiency is not achieved. In the case of the fishery resource, it is quite likely that expansions in demand will ultimately produce overfishing of the resource, which is a negative contribution to national income.

The only solution to the "market failure" is government intervention. Government must find some device to control entry to the resource either by auctioning fishing rights or licenses. Of course, this must be qualified to include tradeoffs between optimum resource allocation versus employment effects.

Externalities such as those described above will become of increasing importance in the area of pollution control and general environmental questions.

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